Testing of a TSI unit – an electronically controlled engine with a gasoline direct injection system

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***Abstract* — The article presents a detailed analysis of the TSI (Turbo Straight Injection) gasoline direct injection system used in the vehicles manufactured by Volkswagen Group. The work presents the characteristic construction elements of this type of engine together with the descriptions of their influence on its operation. Next, it presents the results of engine power, torque, pollution emission levels, and fuel consumption tests conducted for the Skoda Superb 1.8 TSI and a comparison of the results with the results obtained for an equivalent engine with indirect fuel injection – Skoda Superb 1.8 T.**

Keywords — direct fuel injection, electronic engine control, TSI, uniform mixture, petrol engine

I. Introduction

The TSI engine is the next generation of engines with direct fuel injection developed in the Volkswagen Group concern. The first representative of this type of engines is the engine with the capacity of 1.8 dm^3 with turbo injection used successfully in Skoda Superb manufactured in the Czech Republic. The constructors placed the main focus on achieving the highest performance possible with optimal fuel consumption. During the engine design phase, the following assumptions were followed [1]:

a) achieving high mechanical and thermodynamic performance in combination with compact structure,
b) meeting the requirements with respect to environmental protection, noise level, and fume content,
c) meeting the requirements of safety regulations regarding, for example, pedestrian safety or passenger compartment deformation resulting from a head-on crash,
d) reasonable price thanks to the reduction of manufacturing costs,
e) ease of performing repairs and technical servicing,
f) the possibility of longitudinal and transverse positioning in different car model.

II. Construction and Operation of 1.8 TSI Engine

The fuel supply system was slightly changed in comparison to the TFSI version. It consists of a fuel tank, a low-pressure line, a high-pressure pipe, fuel collector and four injectors. The pressure sensor as well as the safety valve and the check valve were removed from the low pressure circuit. The necessary pressure is calculated by the engine controller which controls the pump in the fuel tank. The pump can generate pressure in the range of 0,4÷0,8 MPa. There is no overpressure valve in the high pressure circuit as it was replaced with a fuel pressure regulating valve integrated with the high-pressure pump. It maintains the pressure within the range of 5÷15 MPa (depending on the load), and directs the excess of fuel to the low pressure circuit. Maximum regulator pressure is 20 MPa.

The air supply system is very similar to the system used in the TFSI engine. It consists, respectively, of an air filter, a flow meter integrated with a temperature sensor, an electronically controlled throttling valve, and an intake manifold with flaps that control the air flow. An anemometric flow meter integrated with an intake air temperature sensor is used to measure the amount of air. The frequency modulated signal from it is provided to the controller. The air mass is determined on the basis of a value table recorded in the controller memory [3].

The fume exhaust and reduction system in the TSI engine is constructed in a relatively simple way. A preliminary catalytic converter is placed directly behind the engine, then a two-step Lambda probe is fitted, and the main three-way catalytic converter is placed directly behind it. A broadband probe before the preliminary catalytic converter was not used, as it was replaced with a set of characteristics programmed in the controller memory. Such a solution became possible thanks to the use of uniform mixture (λ=1) for the full range of engine speed (with the exception of the start of a cold engine). In this way, Lambda regulation was considerably simplified.

The level to which the cylinders are filled with fresh air in the TSI engine is increased by means of a supercharger. It is designed in such a way so as to increase the dynamics and, at the same time, to reduce fuel consumption. The supercharger makes it possible to achieve the highest torque value when it is needed the most, that is in any range of rotational speed values. 80 % of maximum torque can be achieved as early as at 1250 r/min, and 100 % - at 1500 r/min [3].

In the TSI engine, identically to the earlier generations of direct fuel injection systems manufactured by the Volkswagen concern, it is possible to shift the position of the intake camshaft. It is only the construction of the shift system that is different. By shifting the camshaft, it is possible to adjust the torque to the engine operation phase and improve the composition of the fumes. The intake shaft can be shifted by 30 ° or 60 ° in relation to the crankshaft.

The 1.8 TSI engine uses the Bosch MED 17.5 engine control module. The hardware and software components have been developed so that they can be used for future projects both for gasoline and diesel engine applications. This allows maximum use with regards to functions and vehicle interfaces independent of the engine combustion configuration. Examples of this include the Electronic Pedal Control and radiator fan activation strategies [3].

III. TESTS AND ANALYSIS OF THE PERFORMANCE OF THE TSI ENGINE

In order to test the performance of the 1.8 TSI engine, nominal power, torque, exhaust emission and fuel consumption tests were performed on the engine. At the same time, the 1.8 T indirect fuel injection engine was tested in order to obtain comparison. Both engines were fitted in the Skoda Superb model with the sedan body type [1].

All the tests were performed in accordance with the European Directive 98/69/EC, on the chassis test stand of one of the vehicle diagnostics point in Poznań.

The NEDC driving test constituted the first part of the tests conducted. It made it possible to determine the amount of pollution emitted and the fuel consumption (*table I*) [2].

TABLE I. SUMMARY OF THE RESULTS OF THE TESTS PERFORMED AND COMPARISON WITH THE DATA PROVIDED BY THE MANUFACTURER AND WITH DIRECTIVE 98/69/EC [2, 4]

Parameters		Test results		Manufacturer's	
		2.0 TSI	2.0 T	2.0 TSI	2.0 T
Nominal power [kW]		110 (6200)	110 (6200)	118 (5000)	110 (5500)
Torque [N·m]		210 (3300)	210 (3700)	250 (1500)	210 (1750)
Fuel consumption according to the NEDC test	City [dm^3/100 km]	10,2	11,4	10,4	11,5
	Road [dm^3/100 km]	6,3	6,6	6,0	6,5
	Average [dm^3/100 km]	7,5	8,7	7,6	8,3
Fume emission according to the NEDC test	CO_2 [g/km]	181	210	180	202
	CO [g/km]	0,184	0,426	< 2,3	< 2,3
	HC [g/km]	0,097	0,068	< 0,2	< 0,2
	NO_x [g/km]	0,069	0,030	< 0,15	< 0,15

The second part of the tests involved determining the speed characteristics of direct injection engines (*fig. 1*) and indirect injection engines including the determination of the maximum nominal power and the maximum torque. The characteristics determined in accordance with Directive 98/69/EC [2].

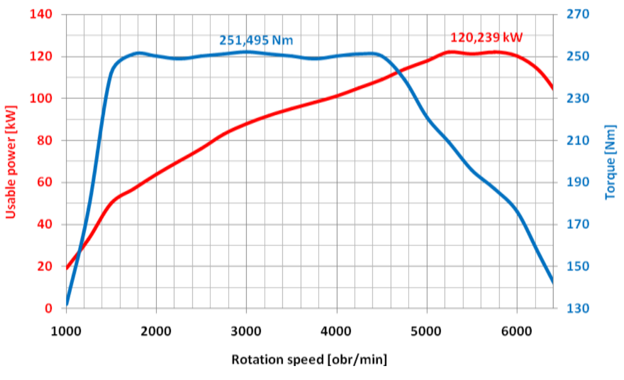

Fig. 1. Skoda Superb 1.8 TSI engine speed characteristics [4]

The tests conducted make it possible to perform the analysis in two different ways. Firstly, the results can be compared with the data provided by the manufacturer. In this case, a clear similarity can be observed (*table 1*). The engine nominal power and torque characteristics depending on the rotational speed determined on the chassis test stand reflect the charts published by the Volkswagen Group concern. Slight differences between the results of the tests performed and the data provided by the manufacturer should be explained, most of all, with differences in the test stands used and with the fact that the cars examined already had a certain mileage greater than zero (about 130 thousand km) – material wear or aging.

In the second case, a comparison of two types of engines was performed: an engine with direct fuel injection and an engine with indirect fuel injection. The analysis shows clearly that the parameters of the engine with indirect fuel injection are worse than the parameters of the engine with direct fuel injection. The nominal power and the torque values are considerably higher for the 1.8 TSI engine [6].

In certain cases, fuel consumption differs considerably from the data provided by the manufacturer both for the car with direct fuel injection as well as for the one with indirect fuel injection. However, even considering the differences in comparison to manufacturer data, the 1.8 TSI engine consumes 1,2 dm^3/100 km less petrol than the 1.8 T engine.

Pollution emission with reference to hydrocarbons and oxides of nitrogen is considerably lower for the car with indirect fuel injection. Despite that fact, higher pollution emission levels for the engine with direct fuel injection are well within the limits specified in the standard. Carbon dioxide emission for both engines does not meet the requirements of the standard but the engine with direct fuel injection is comparatively better. It is worth noticing that the emission of carbon monoxide is over two times lower in the 1.8 TSI engine in comparison to the 1.8 T engine [4].

IV. SUMMARY

The analysis of the nominal power and torque characteristics obtained leads to a clear statement that the characteristics demonstrated by the engine with direct fuel injection are better. Cars equipped with this type of engines are characterized by improved dynamics and flexibility which has a positive influence on the driving comfort.

The tests conducted and the comparative analysis of their results performed showed that direct fuel injection systems are superior to indirect fuel injection systems. The present work has proved that it is possible to achieve higher engine nominal power and torque values at relatively lower fuel consumption and lower carbon monoxide emission to the atmosphere.

Direct fuel injection engines are now becoming more and more popular. More and more automotive concerns start to use this type of engines in their cars. The advantages of direct fuel injection systems presented in the present work indicate that they can replace indirect fuel injection systems and become serious competition for diesel engines with respect to fuel consumption and fume emission [1, 4].

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